LARP CM18/HiLumi LHC Meeting

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High Luminosity LHC

Cooling aspects for Nb_3Sn Inner Triplet quadrupoles and D1

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Overview

- Baseline: Points to be addressed for magnet cooling at 1.9 K
- Plan B: cooling 4- 4.5 K using supercritical helium
- Typical to be expected T-map for coil with cooling at 1.9 (using 11 T dipole design as starting point)

Points to be addressed for Superfluid Helium

1. Generic cold mass requirements for cooling IT+D1
2. Estimated cold source temperature and T-margin for heat extraction
3. Generic cold mass design features for coil cooling and quench pressure protection

1: Typical layout for Nb_3Sn (140 mm and 120 mm aperture combined)

Magnet	length (m)	variation (m)
Q1	**7.445**	**0.255**
Q1 t Q2	3.305	0.255
Q2a	**6.38**	**0.19**
Q2a to Q2b	1.775	0.135
Q2b	**6.38**	**0.19**
Q2b to Q3	3.305	0.255
Q3	**7.445**	**0.255**
Q3 to D1	8.2	0
D1	**10**	**0**
Total	**54.2**	**1.5**

•The *total length variation* between 140 mm or 120 mm aperture option is *irrelevant* for the general cooling design.

•Typically a *length of ~ 55 m* will be considered for all cooling options.

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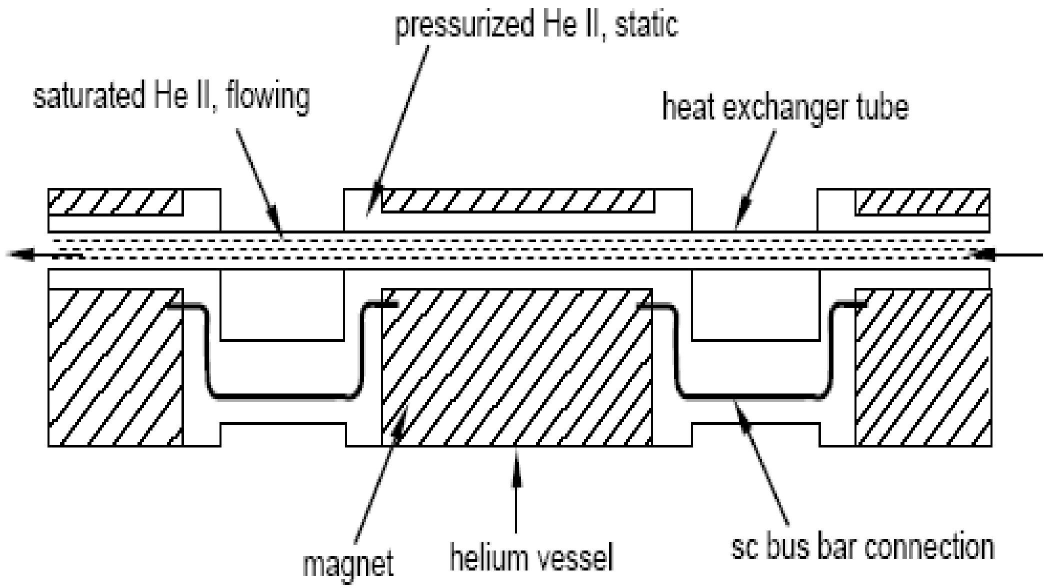
1: 2-Phase HeII heat exchanger (our « cold source »)



Sizing based on *[ref 1]* :
- Minimum heat exchange area
- Acceptable 2-phase flow ΔP
- Vapour flow below 2-phase flow instability threshold of 7 m/s

Two parallel bayonet heat exchangers made out of Cu pipes passing in-interrupted *(i.e. at one level)* through all Inner Triplet cold masses and interconnects. *Not required for D1*

- *2 x ID 86 mm (800 W)*
- *design pressure 20 bar external*

1: additional generic cold mass features

- Balancing heat load longitudinally will require ≈200 -300 cm^2 (800 W) *section of helium in the Inner Triplet cold masses*
- D1 will need ≈150 cm^2 section of helium for conduction cooling through Q3.
- Quench discharge will require ≥ 50 cm^2 smooth pipe equivalent longitudinal passage
- Cool-down and warm-up will require ≥ 50 cm^2 smooth pipe equivalent longitudinal passage

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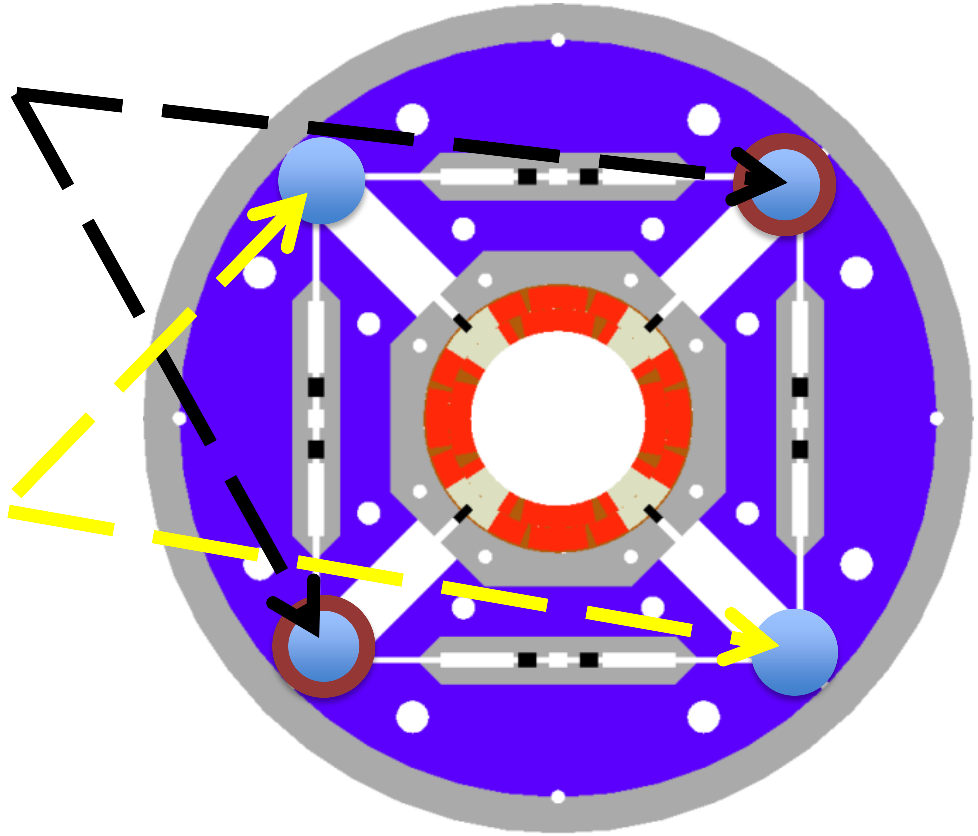
1: Generic cold mass requirements

- 2 // HX ID 86 mm for IT
- Free section of helium

  ≈200 - 300 cm^2 for IT,

  ≈150 cm^2 for D1
- ≥ 50 cm^2 smooth pipe equivalent longitudinal passage (quench, cool-down/warm-up)

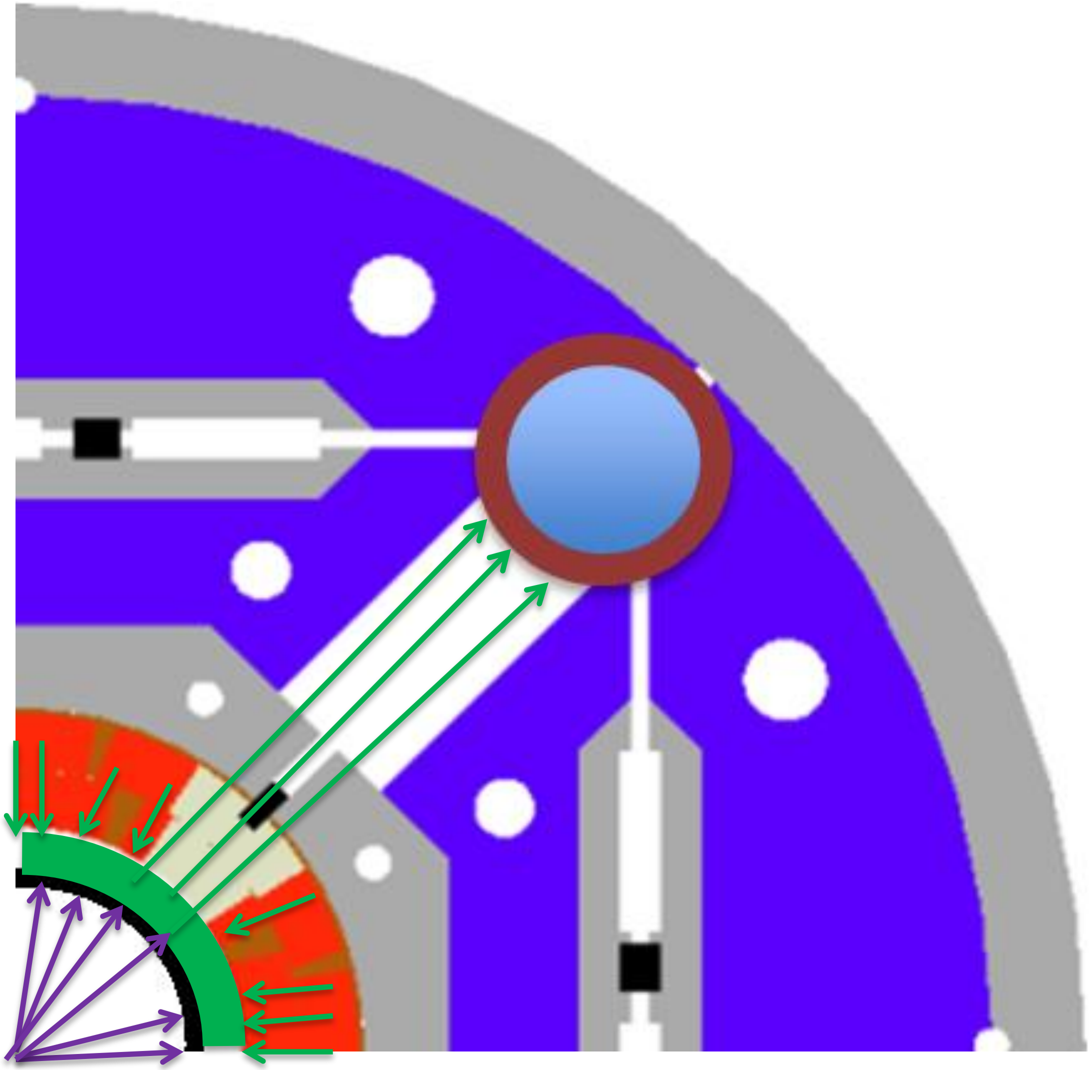


3: Coil cooling and quench pressure

•Heat from the coil area (green) and heat from the beam pipe (purple) combine in the annular space between beam pipe and coil and escape radial through the magnet "pole" towards the cold source → *"pole & collar" need to be "open" (first guess ≈ 4 % confirmed ok)*

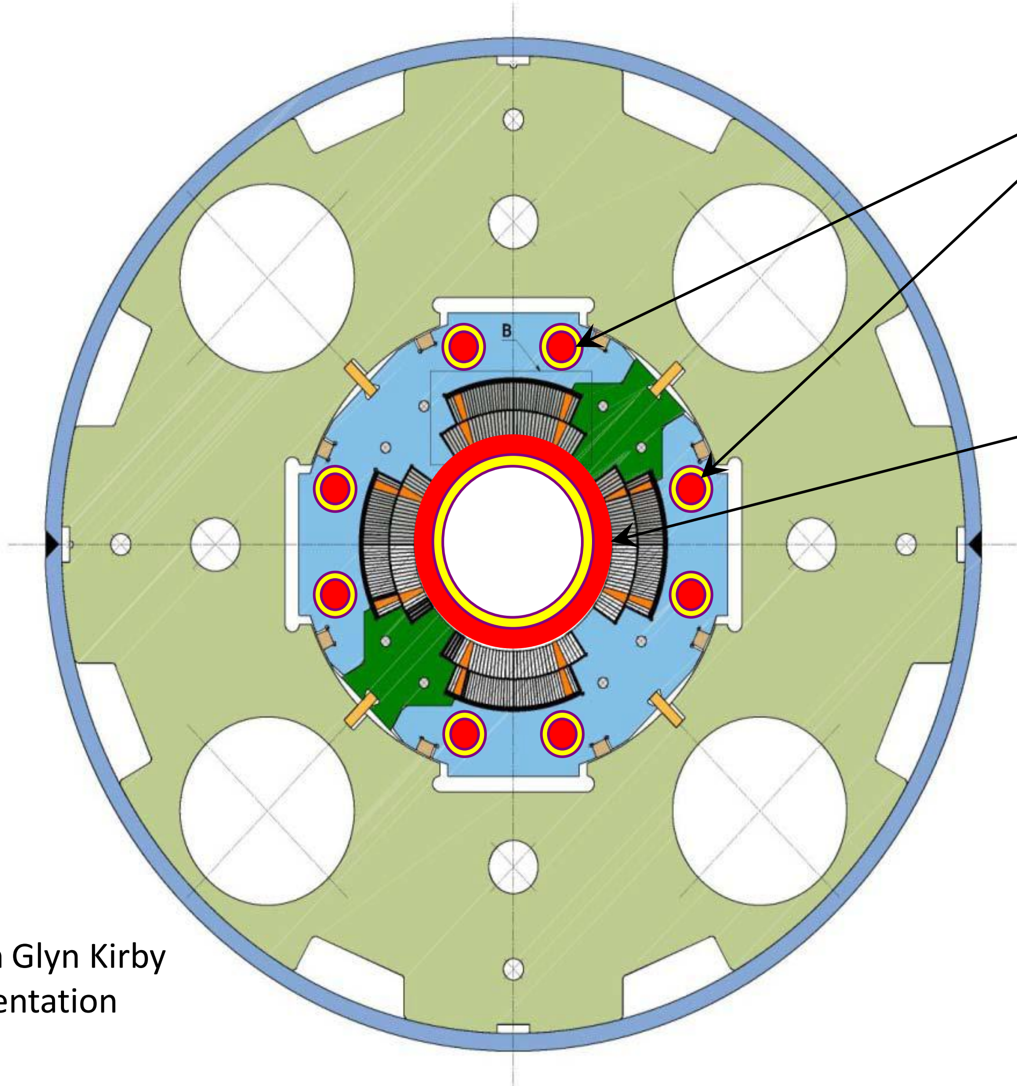
•Longitudinal extraction via the annular space is in superfluid helium, with T close to T_{λ} and with magnets up to 7 m long not reliable → *"pole" & collar need to be "open"*

•Due to the relative incompressible nature of HeII in order to prevent quench induced pressure built up far exceeding 20 bar around the beam pipe → *"pole" & collar need to be "open"*



≥ 1.5 mm annular space

Plan B: cooling 4- 4.5 K using supercritical helium



Distributed pipes outside the magnet

Annular supercritical helium flow inside the magnet

All the channels are supposed to be supplied in parallel so the diameter of the outside pipes has to be adapted to obtain the same pressure drops than the annular channel

Mass flows are ≈150 g/s

Option looks quite feasible, will be detailed by CEA-Grenoble

From Glyn Kirby presentation

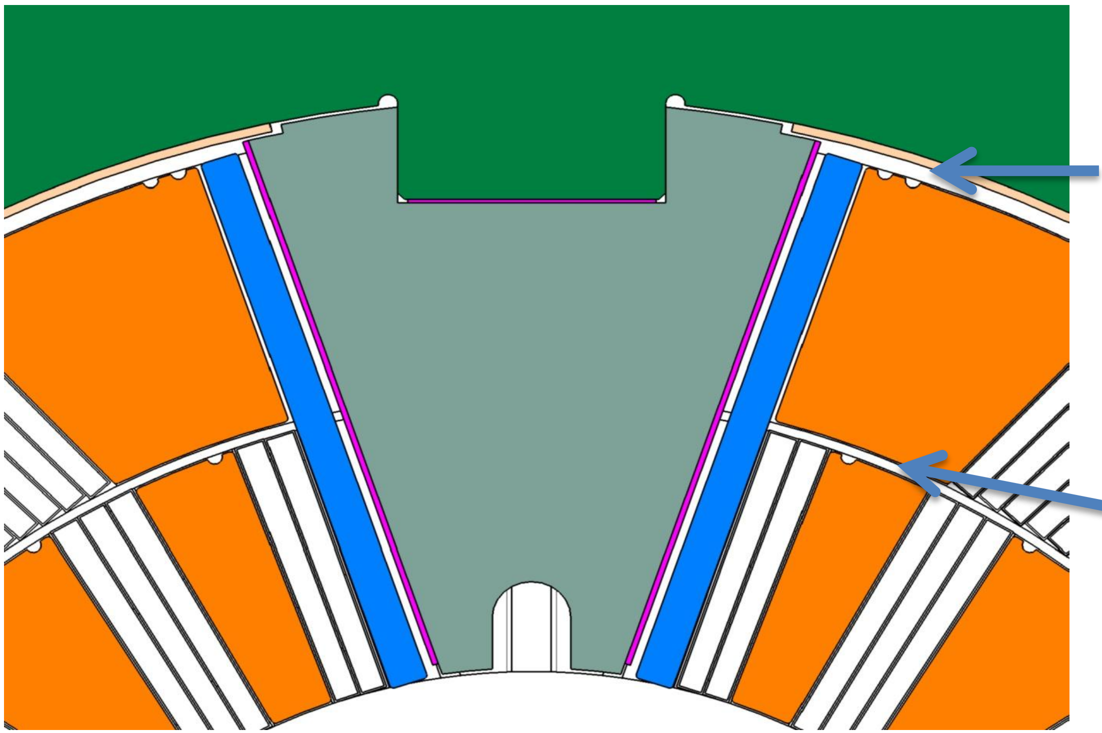
LHC

Expected Temperature Profile in Coils

Assumptions:

1. HQ, as concerns the coils, very similar built (thermally) as the 11 T-dipole design
2. A power distribution similar to F. Cerutti's calculations for the LHC-Phase-I upgrade multiplied by a factor 2.5: 8 mW/cm^3 peak on the central part of the inner layer.
3. Power with respect to the inner layer peak; 1/4 on the outer layer and on the outlying parts of the inner layer, 1/8 on the outlaying parts of the outer layer (see next slide).
4. 1.5 mm annular gap (free space for helium) between coil and beam-pipe
5. 4 % open pole
6. 1 single, asymmetrically placed heat exchanger
7. 1.9 K cold source in heat exchanger

Coil insulation used for calculations



Collars: 6 % open

Pole : 4% open

2nd layer – collars:
2x0.1 mm of G-10
+ 5x0.125 mm kapton
+ 0.5 mm stainless-steel

1st – 2nd layer:
3x0.168 mm of G-10

Cable: 0.1 mm G-10

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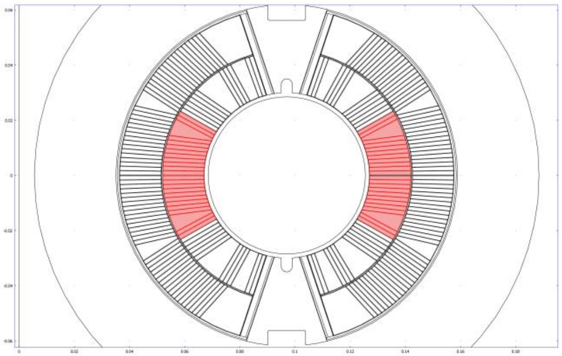
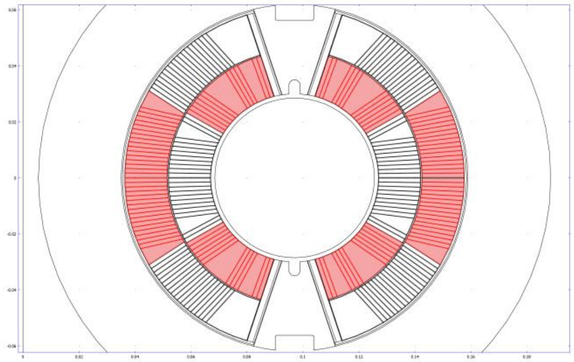
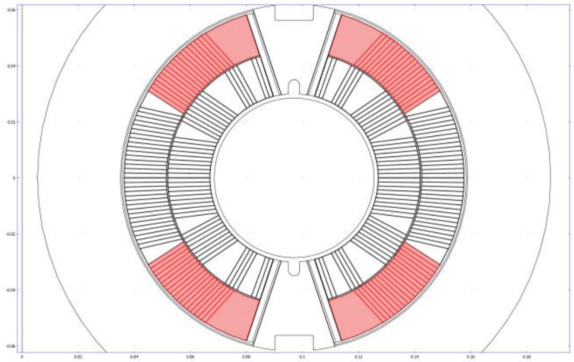
Relative power distribution over the coils



100 %



25 %



12.5 %

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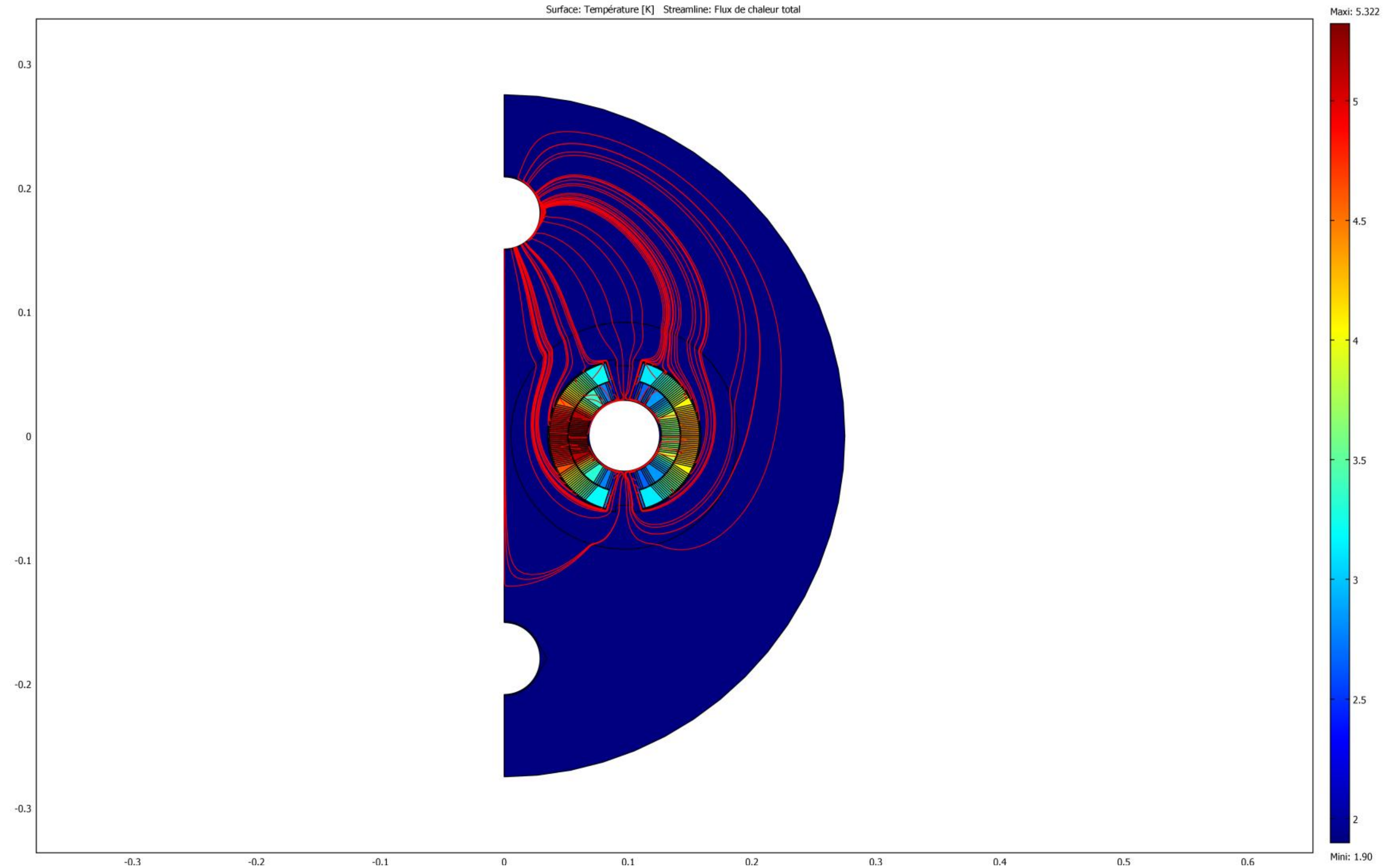
Simulated T-ditribution at 8 mW/cm^3 peak power in central part of inner layer (1/3)



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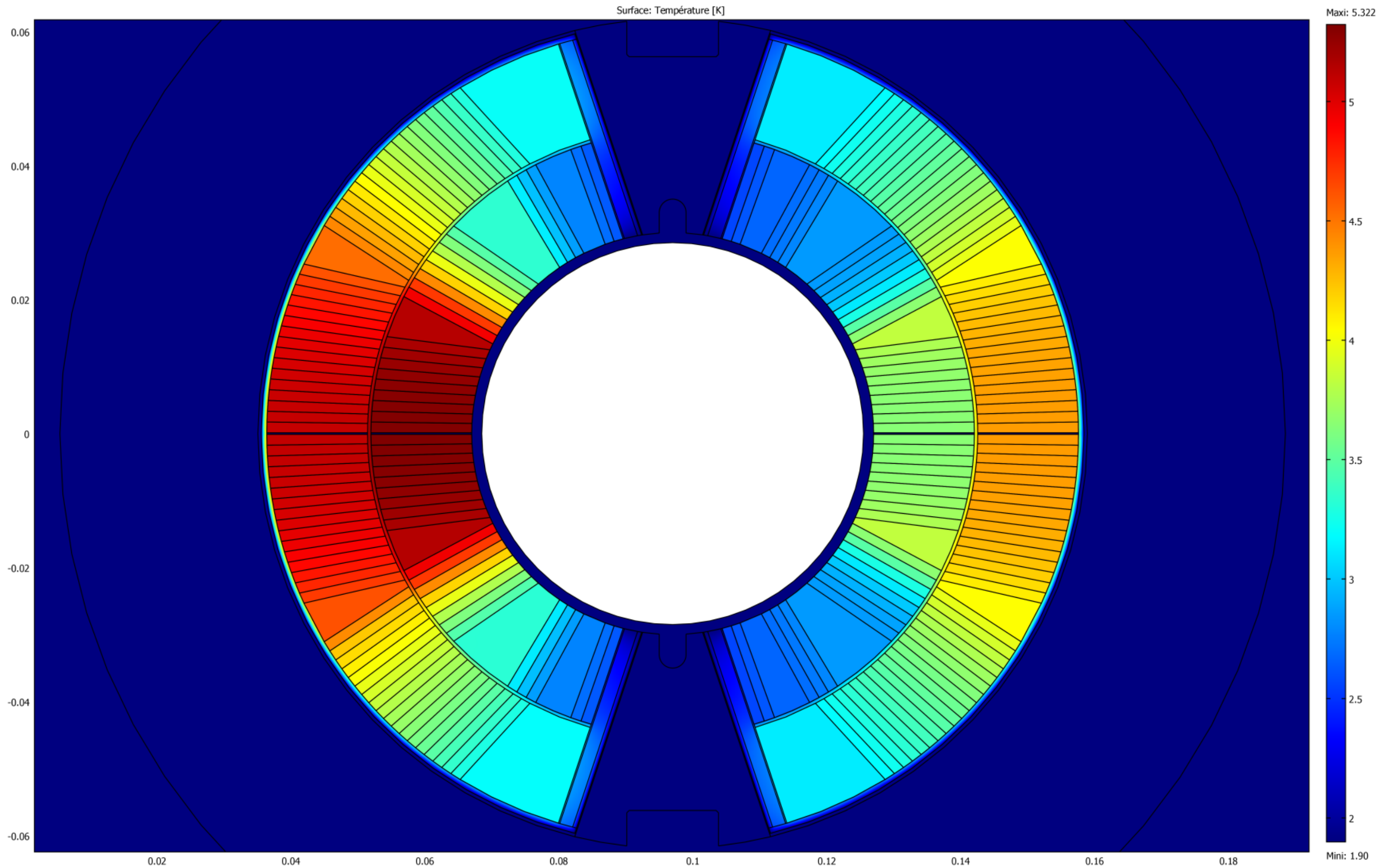
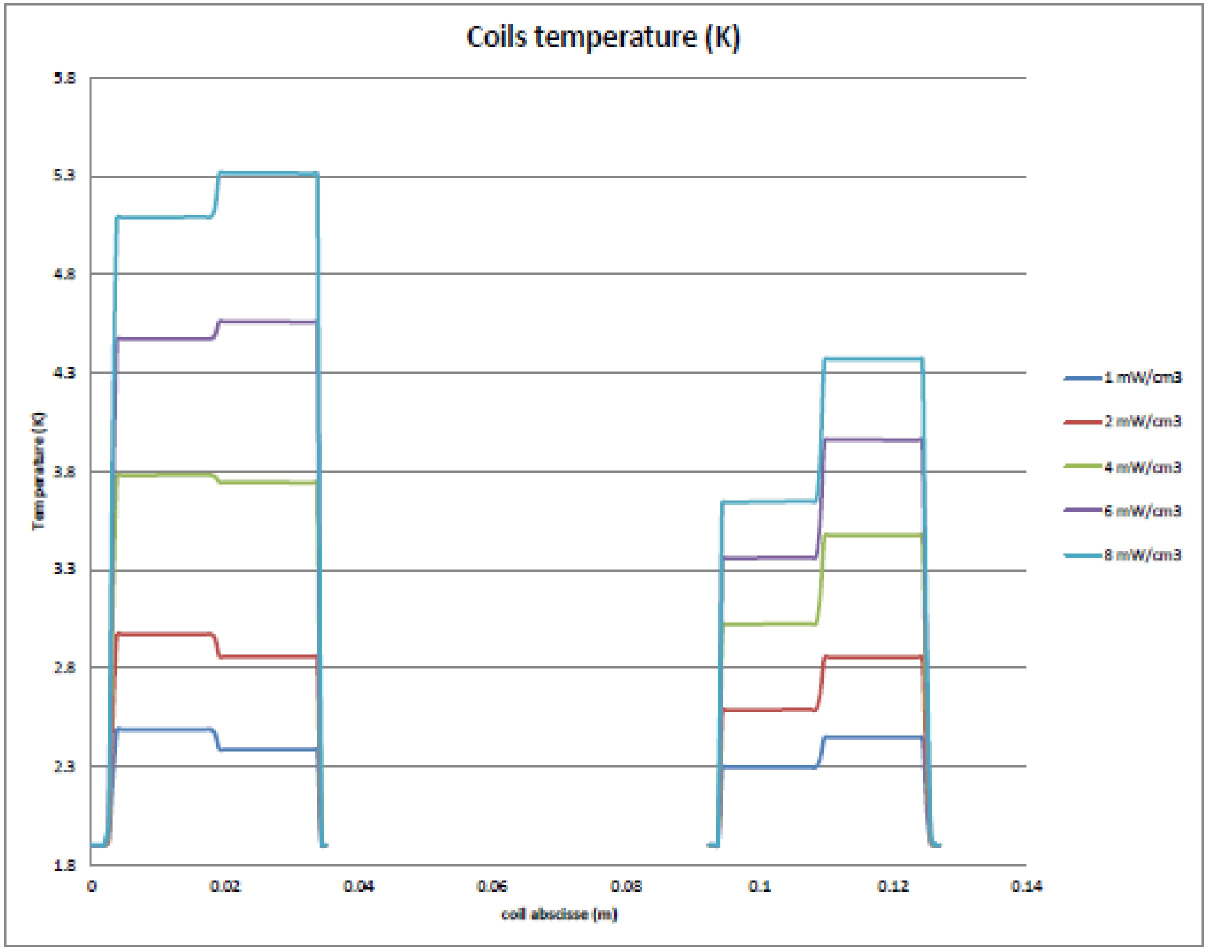
Simulated T-ditribution at 8 mW/cm^3 peak power in central part of inner layer (2/3)



Simulated T-ditribution at 1 to 8 mW/cm^3 peak power in central part of inner layer (3/3)



T profile through the mid-plane

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Main Observations

- 1.5 mm annulus is enough (we have seen it breaks down at smaller values, to be detailed)
- 4 % open pole is enough (we have seen it breaks down at smaller values, to be detailed)
- Asymmetry in coil T-profile reflects the asymmetry of the helium heat flow outside of the coil-pack (~ 1 K could be gained by optimizing this)
- Main T-losses seen at layer to collar, layer to annular space and at inter-layer interfaces are due to the specific cable insulation used (G10 in simulation), and any additional interface materials used.
- Almost identical results for cold source at 2.0 K.
- *Modeling for real HQ geometry, cable insulation and coil pack to be done next.*

Summary (1 of 3)

- The features listed are essential for an accelerator ready magnet and should be implemented.
- Values given strongly dependent on final heat load.
- Values need to be confirmed by "closing the loop" with the heat load assessment and by increasingly detailed thermal models.

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Summary (2 of 4)

- 2 // bayonet heat exchangers made out of Cu pipes passing in-interrupted (i.e. at one level) through all cold masses and interconnects: 2 x ID 86 mm (800 W), design pressure 20 bar external for IT
- Free section of helium ≈200 - 300 cm^2 for IT
- Free section of helium ≈150 cm^2 for D1
- ≥ 50 cm^2 smooth pipe equivalent longitudinal passage

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Summary (3 of 3)

- “pole & collar” need to be “open” by ≈ 4 %
- Free annular space between beam pipe and coil ≥ 1.5 mm.
- *Modeling for real HQ geometry, cable insulation and coil pack to be done next (~ 1 month) so that cable insulation and magnet geometry optimization for cooling can be done.*

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References

1. CERN-ATS-2011-020, “The Cryogenic Design of the Phase I Upgrade Inner Triplet Magnets for LHC”, van Weelderen, R (CERN) ; Vullierme, B (CERN) ; Peterson, T (Fermilab), 23rd International Cryogenic Engineering Conference, Wroclaw, Poland, 19 - 23 Jul 2010

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